

Using fractal analysis to classify stratigraphic units

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Overview

Introduction to fractals

Fractal analysis of signals

Connections to geology

Scientific motivation

Dataset

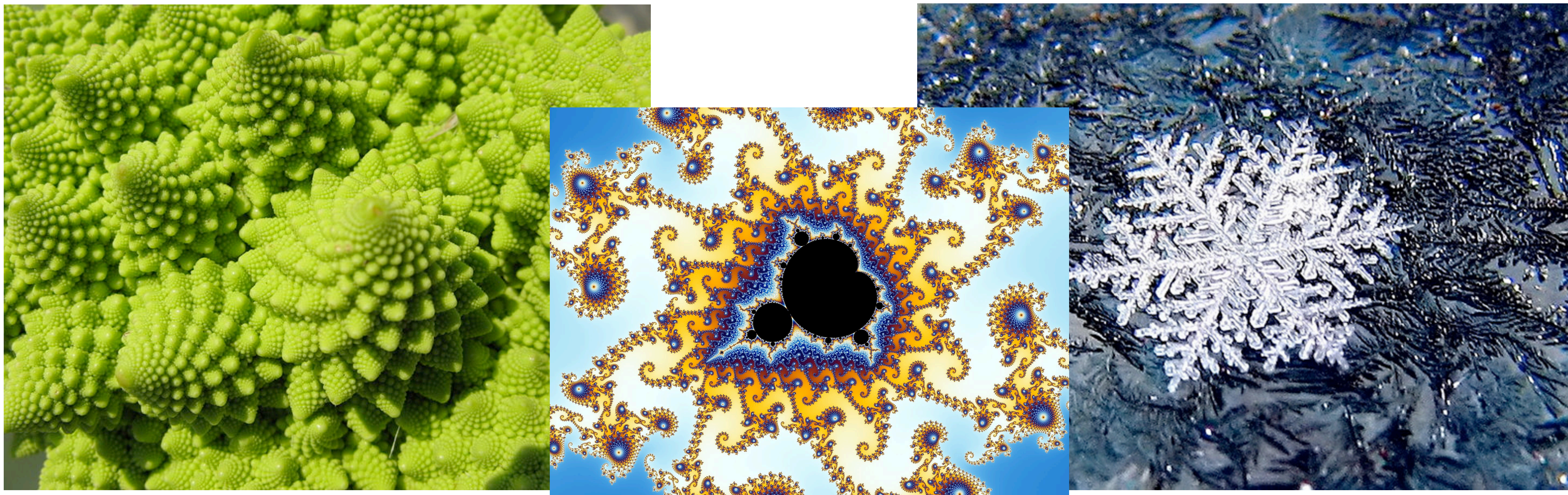
Results

Analysis/conclusions

Introduction to fractals

A natural phenomenon or mathematical set that repeats itself at every scale.

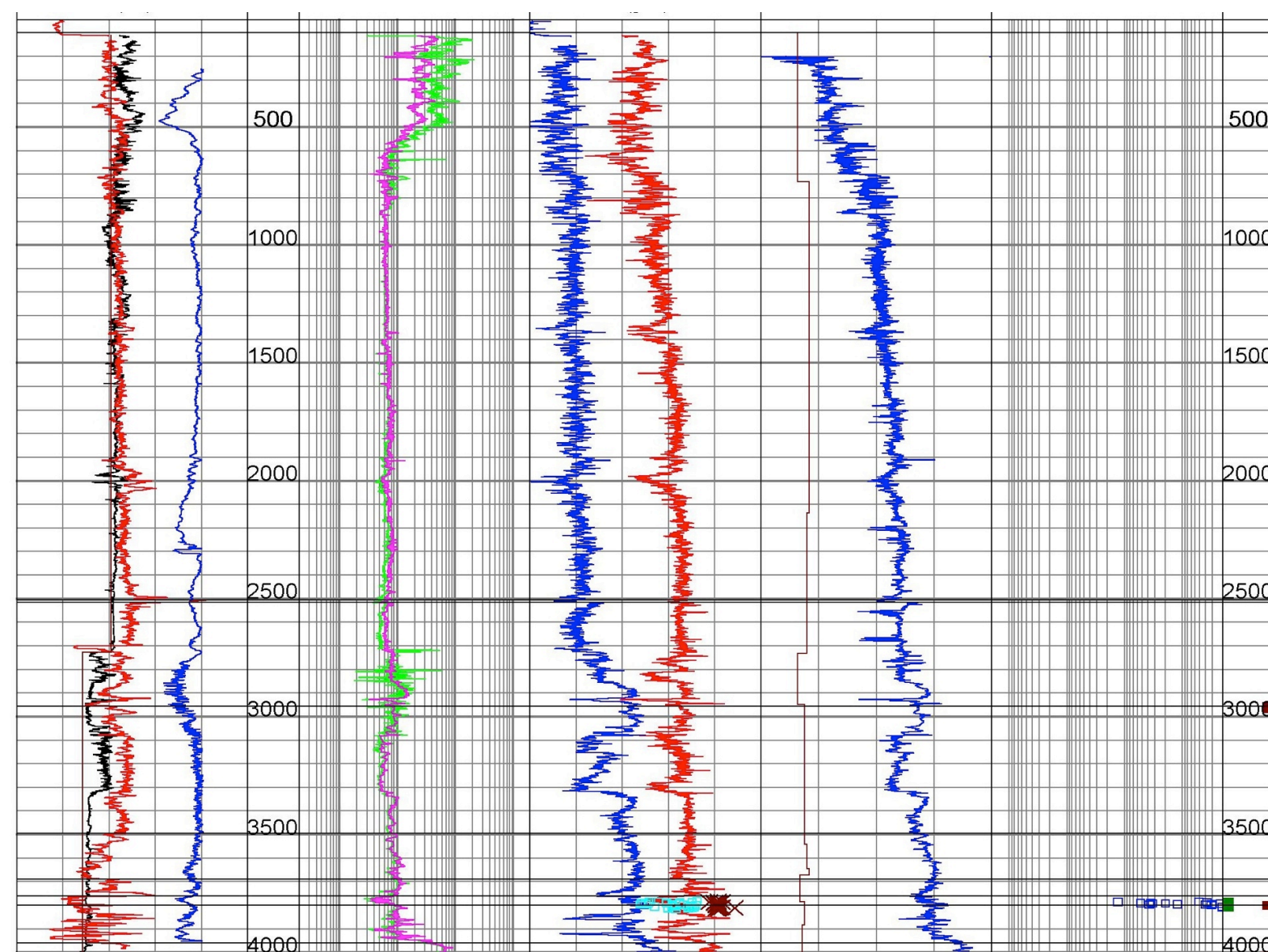
<http://en.wikipedia.org>



<http://www.wired.com/2010/09/fractal-patterns-in-nature/>

Fractal Geophysics

Sedimentary layers are formed by random depositional processes that occur across different timescales.



<http://energy.cr.usgs.gov>

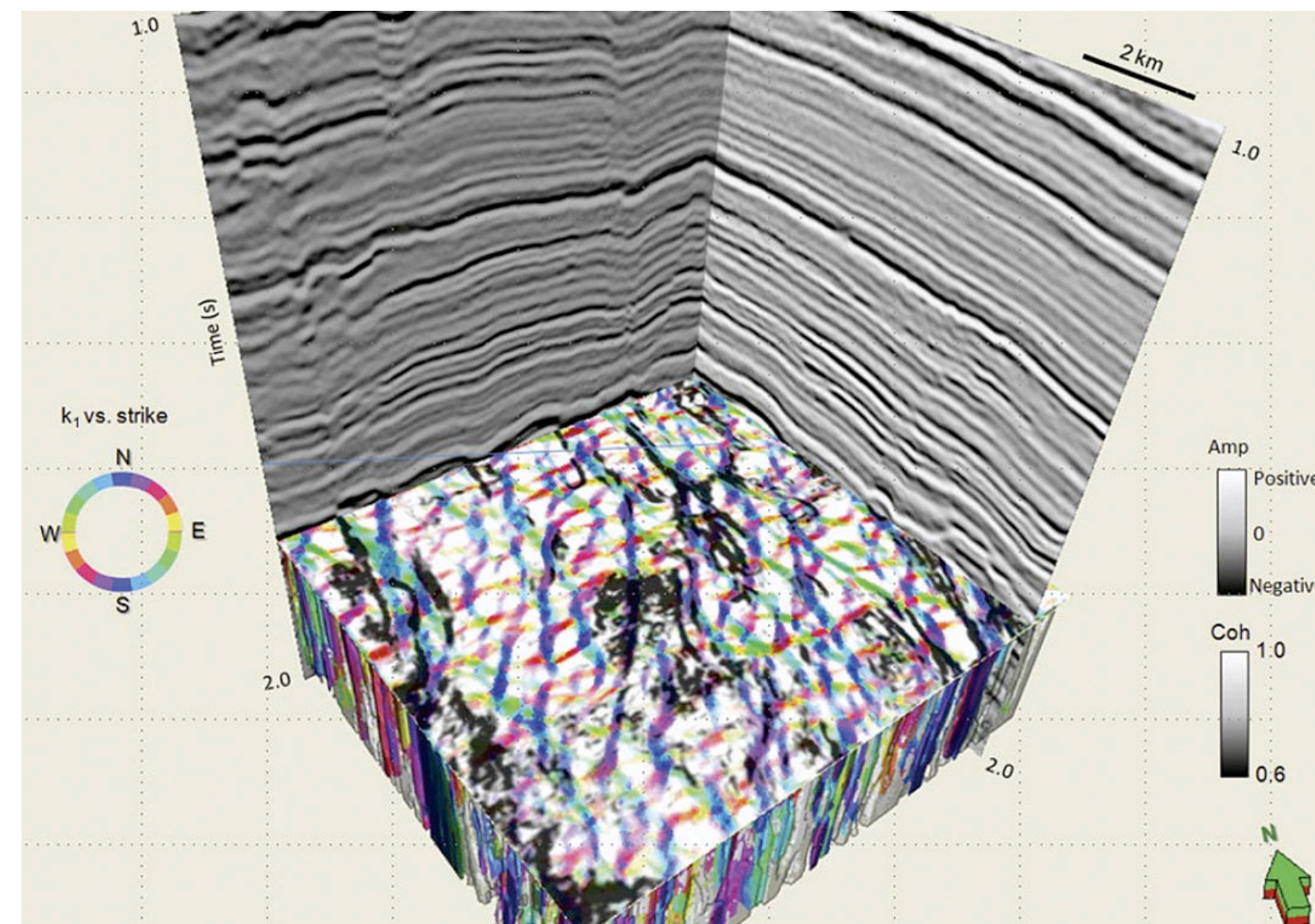
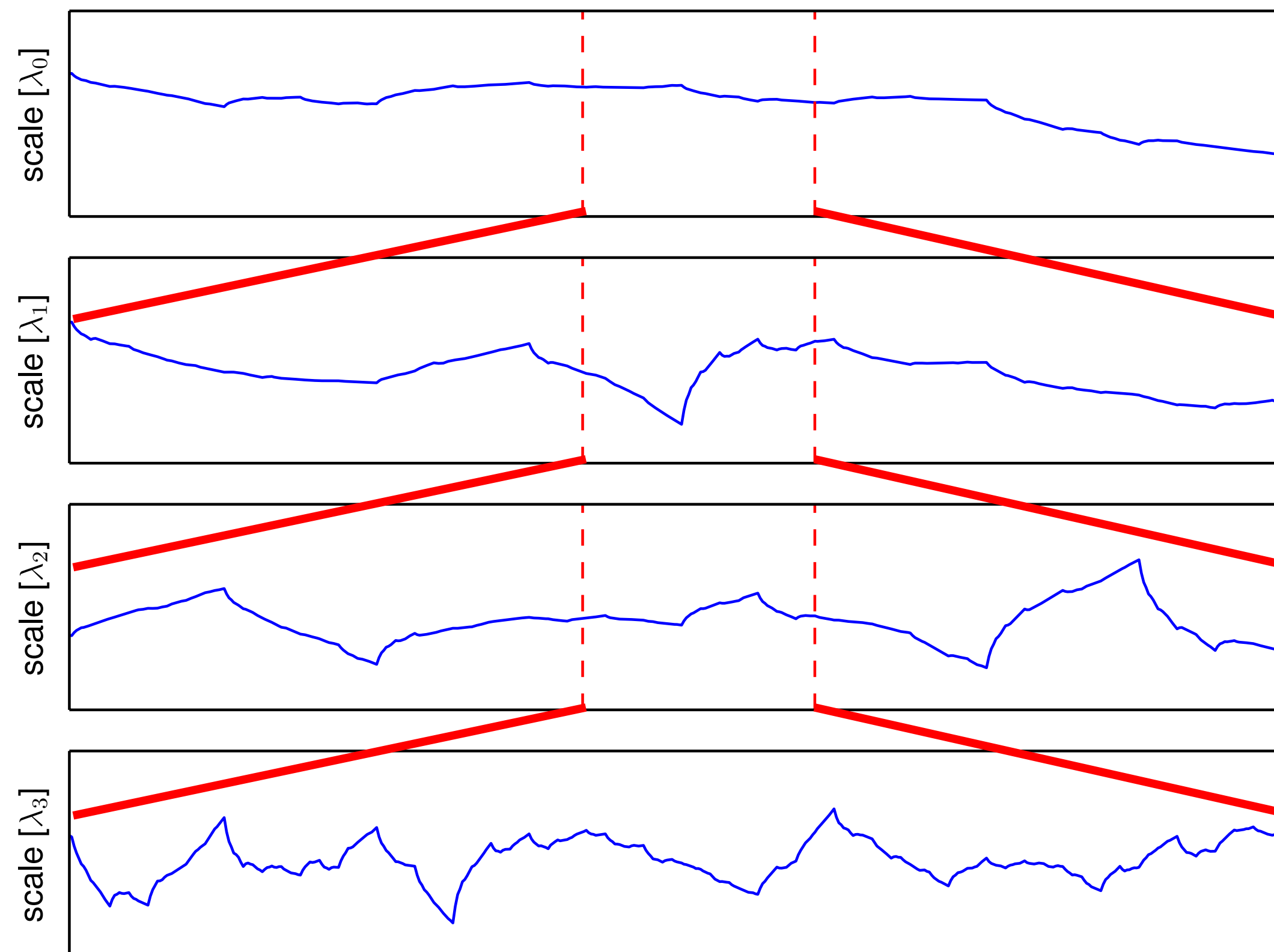


Figure from Chopra and Marfurt [2]

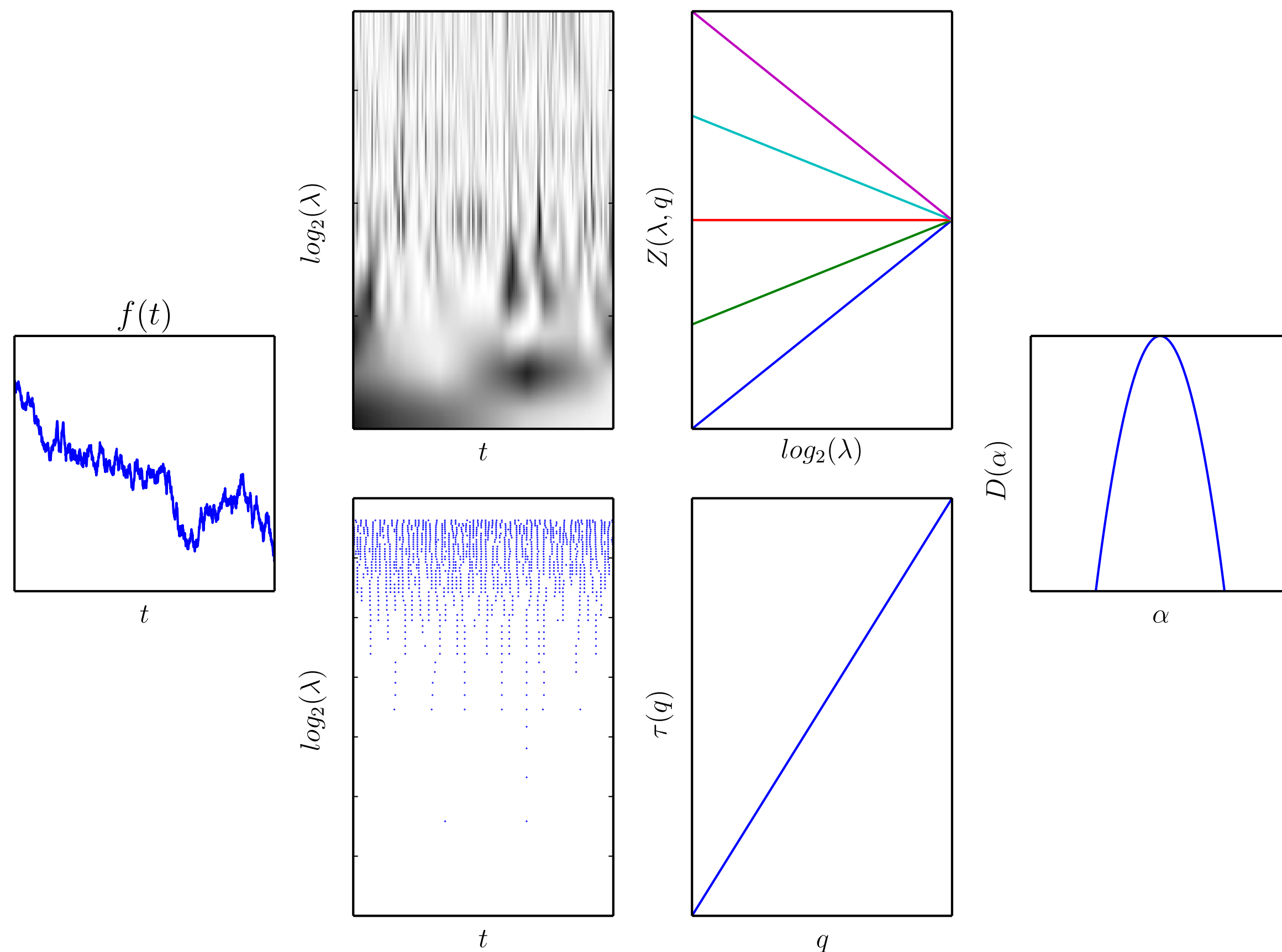
Fractals in signals

Self-similarity is now defined by the signal statistics at each scale



statistically multi-fractal

Multifractal signal analysis



1. wavelet transform:

$$x(t) \rightarrow Wx(u, \lambda)$$

2. modulus maximum (peak filter):

$$|Wx(u_p, \lambda)|$$

3. partition function

$$Z(\lambda, q) = \sum_p |Wx(u_p, \lambda)|^q$$

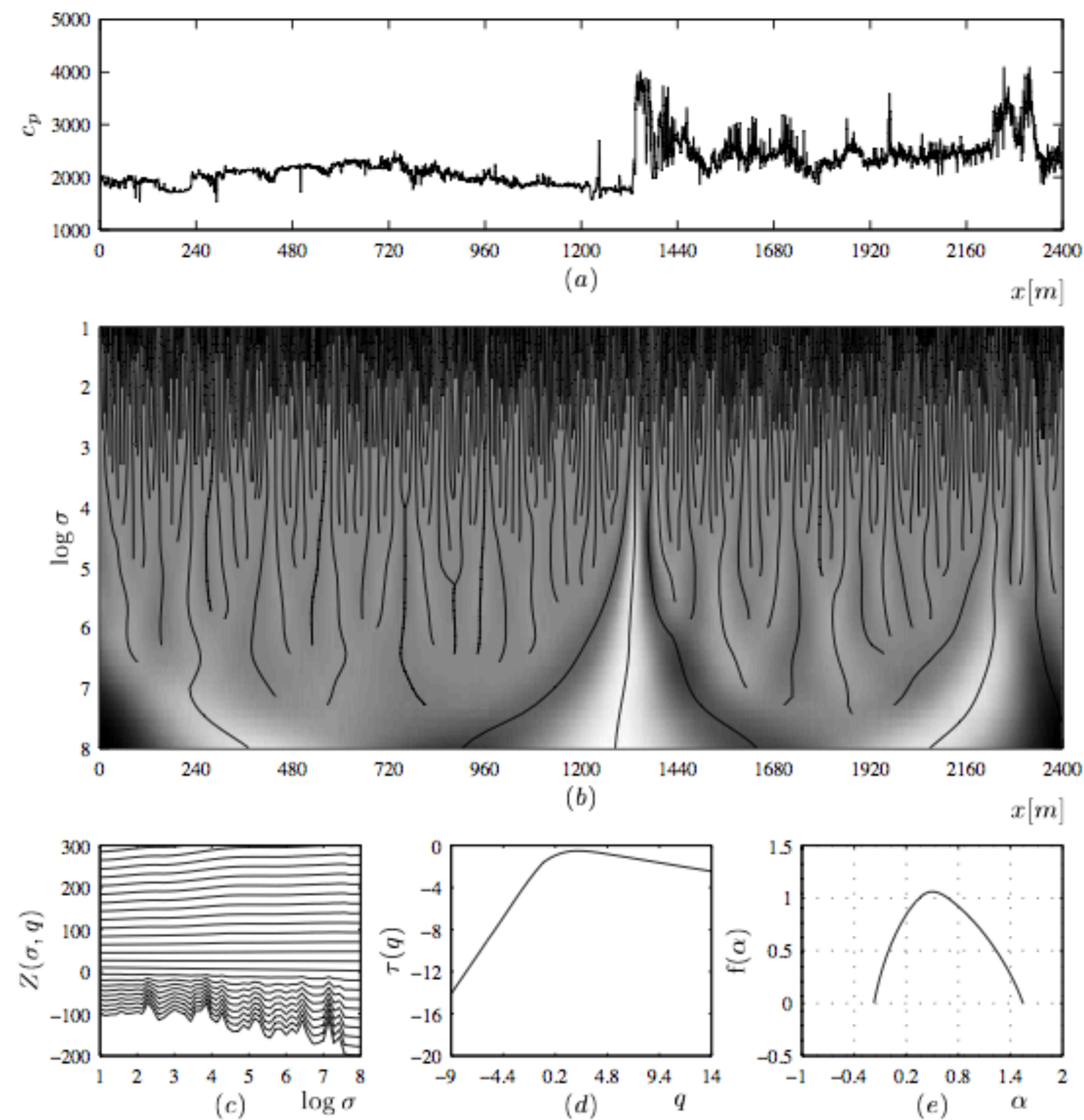
4. scaling exponent

$$\log_2 Z(q, \lambda) \approx \tau(q) \log_2 \lambda + C(q)$$

5. singularity spectrum

$$D(\alpha) = \min_{q \in \mathbb{R}} (q(\alpha + 1/2) - \tau(q))$$

Multifractal log analysis



Well logs are multifractal signals (Herrmann, 1997)

Analyzed for *global* fractal properties

Requires many samples

Multifractal analysis - Summary

A rigorous mathematical foundation for multiscale analysis

Used to show multifractal nature of well logs

Complicated analysis procedure

Requires many samples, provides *global* characteristics

We seek a simpler methodology to extract local multifractal information from signals

Fractal Signal Analysis - Scattering Transform

Takes the form of a pre-trained convolution neural network

Based on windowed wavelet transforms

- multiscale
- fast

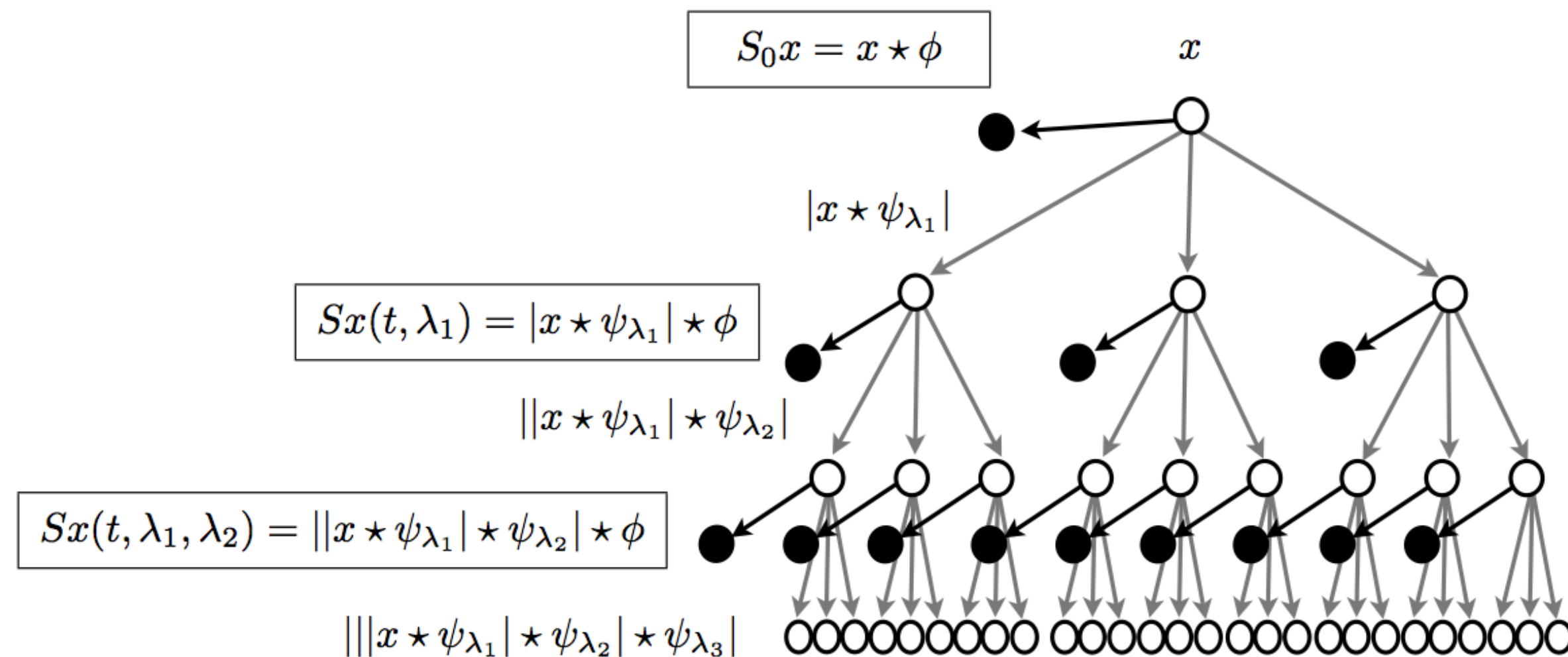
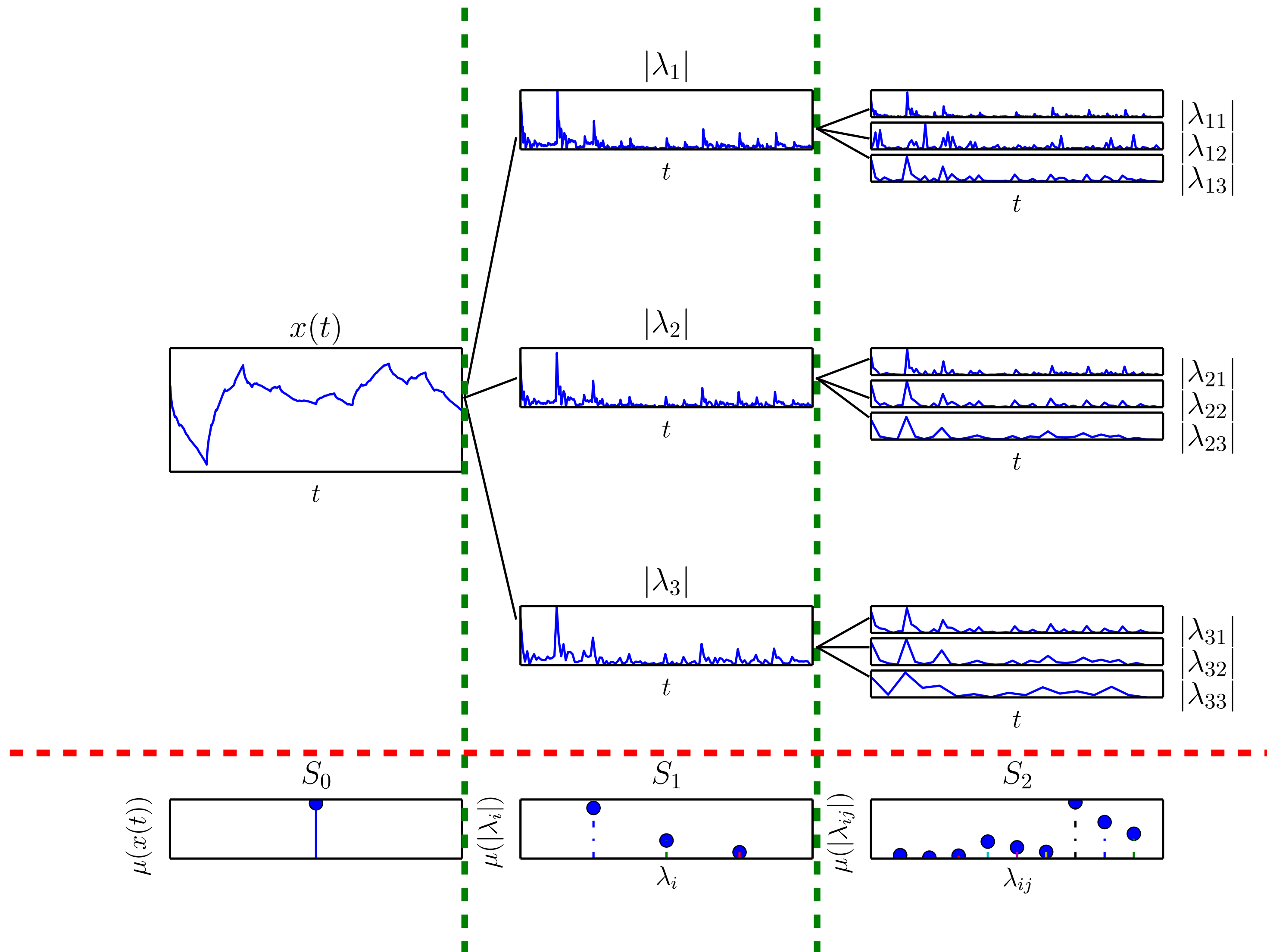


Figure from Anden and Mallat [1]

Fractal Signal Analysis - Scattering Transform



Scientific Questions and Methodology

Can stratigraphic units be classified by fractal statistics?

- Is the scattering transform a useful tool for geo-fractal analysis?

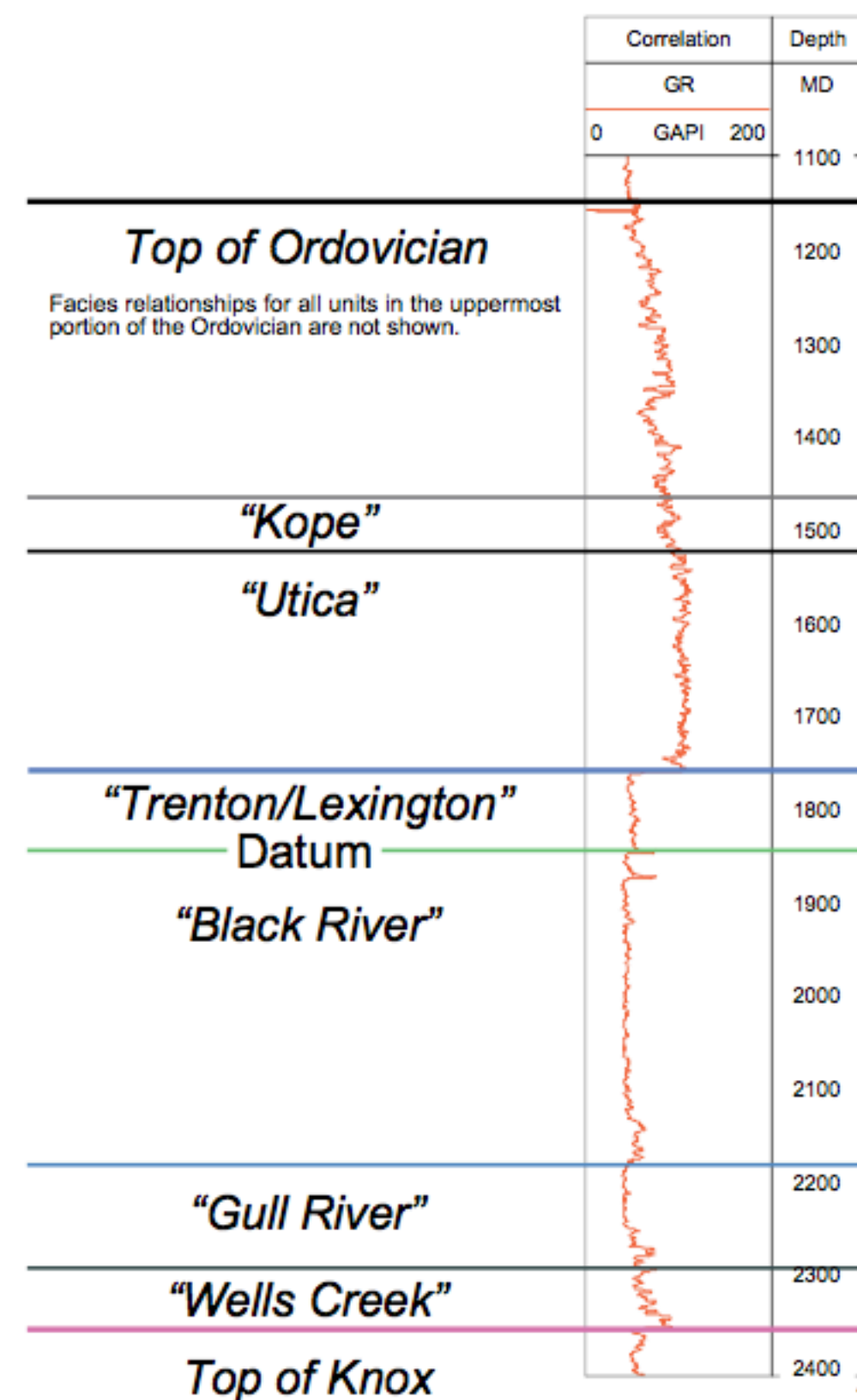
Methodology

- Well logs with labelled stratigraphic units
- Train a classifier using scattering coefficients as features
- Assess success of classification of test data

Dataset - Trenton Black River Project

- Multi-faceted resource assessment model of Trenton-Black River reservoirs in New York, Ohio and West Virginia
- One of very few open access labelled well log data sets
<http://www.wvgs.wvnet.edu/www/tbr/default.asp>
- Made use of 80 gamma-ray logs with labelled stratigraphic units
- **FULL DISCLOSURE - AT THIS POINT I KNOW VERY LITTLE ABOUT THE GEOLOGY OF THIS PROJECT**

Dataset - Trenton Black River Project

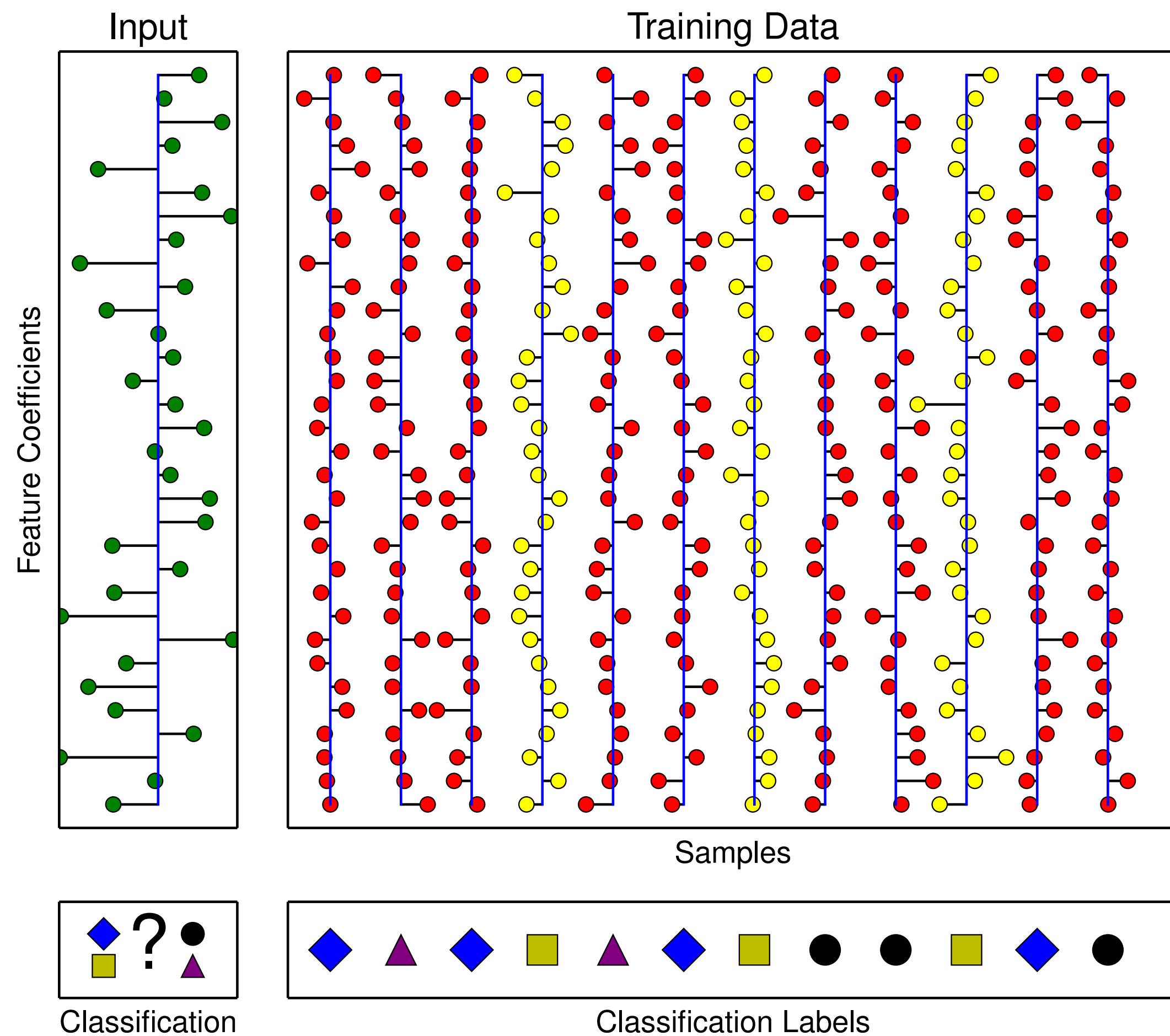


Due to pinch outs and limited data, only the 5 largest stratigraphic units were used for classification

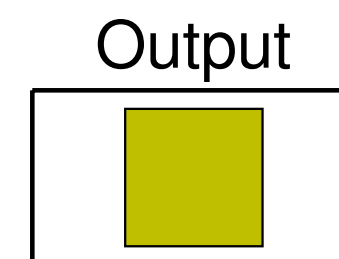
- Ordovician
- Kope
- Black River
- Trenton/Lexington
- Utica

Figure from Trenton Black River Project [3]

Classifier - Nearest Neighbour

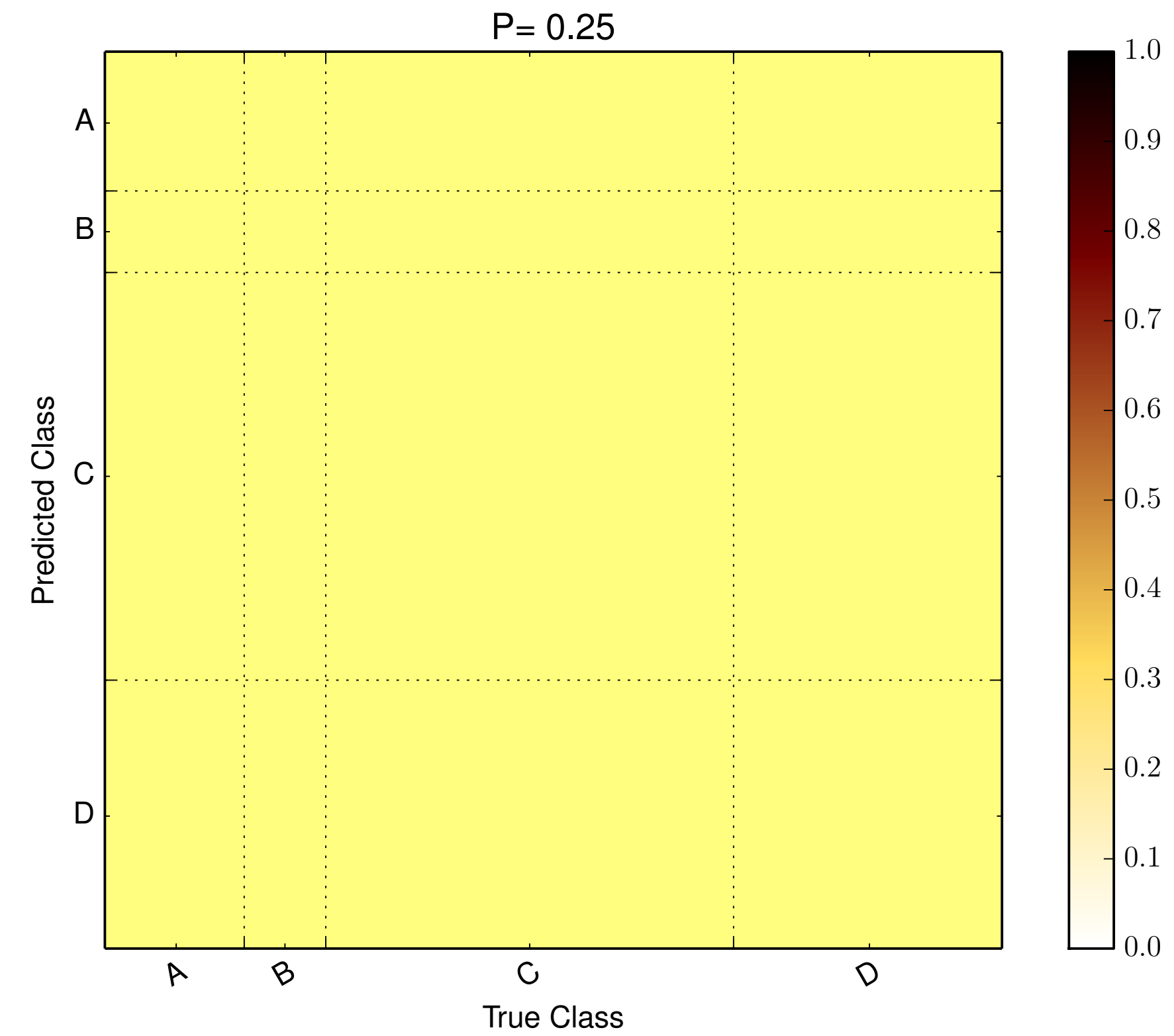
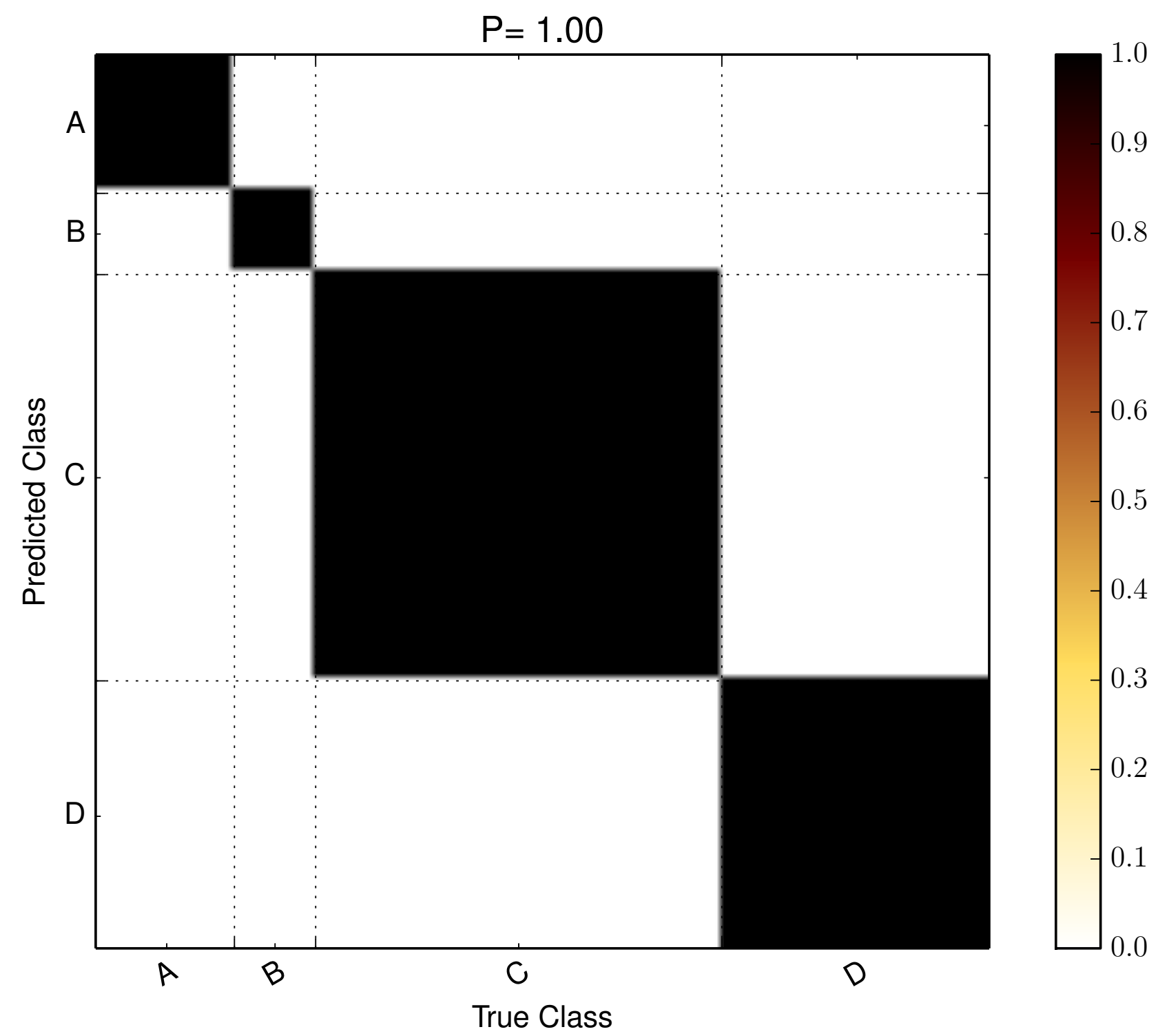


- Extract "feature" vectors
- S_0, S_1, S_2 scattering coefficients



Simple classifier, but does not obfuscate the data

Results - Confusion Matrix



Results

Scattering Transform

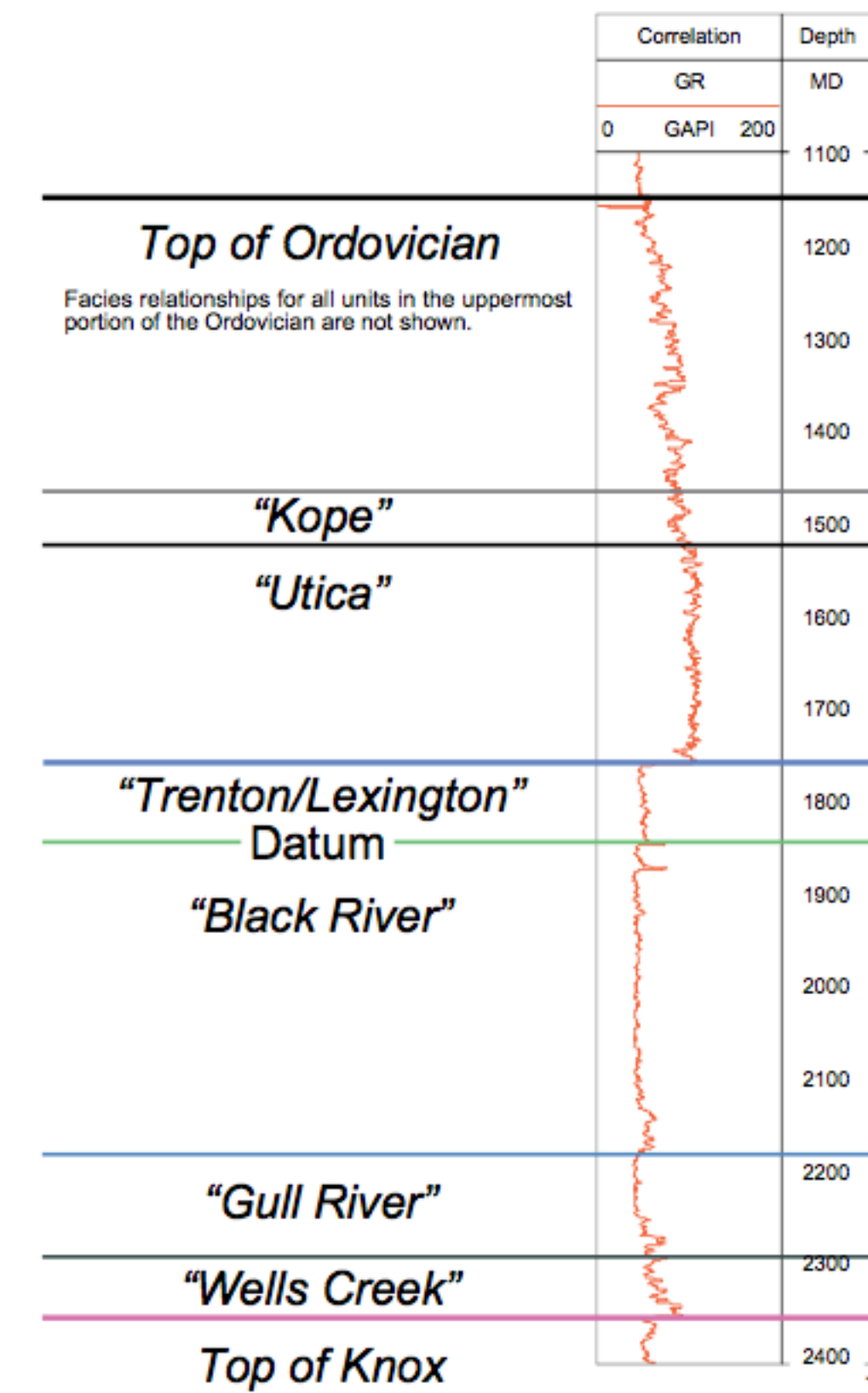
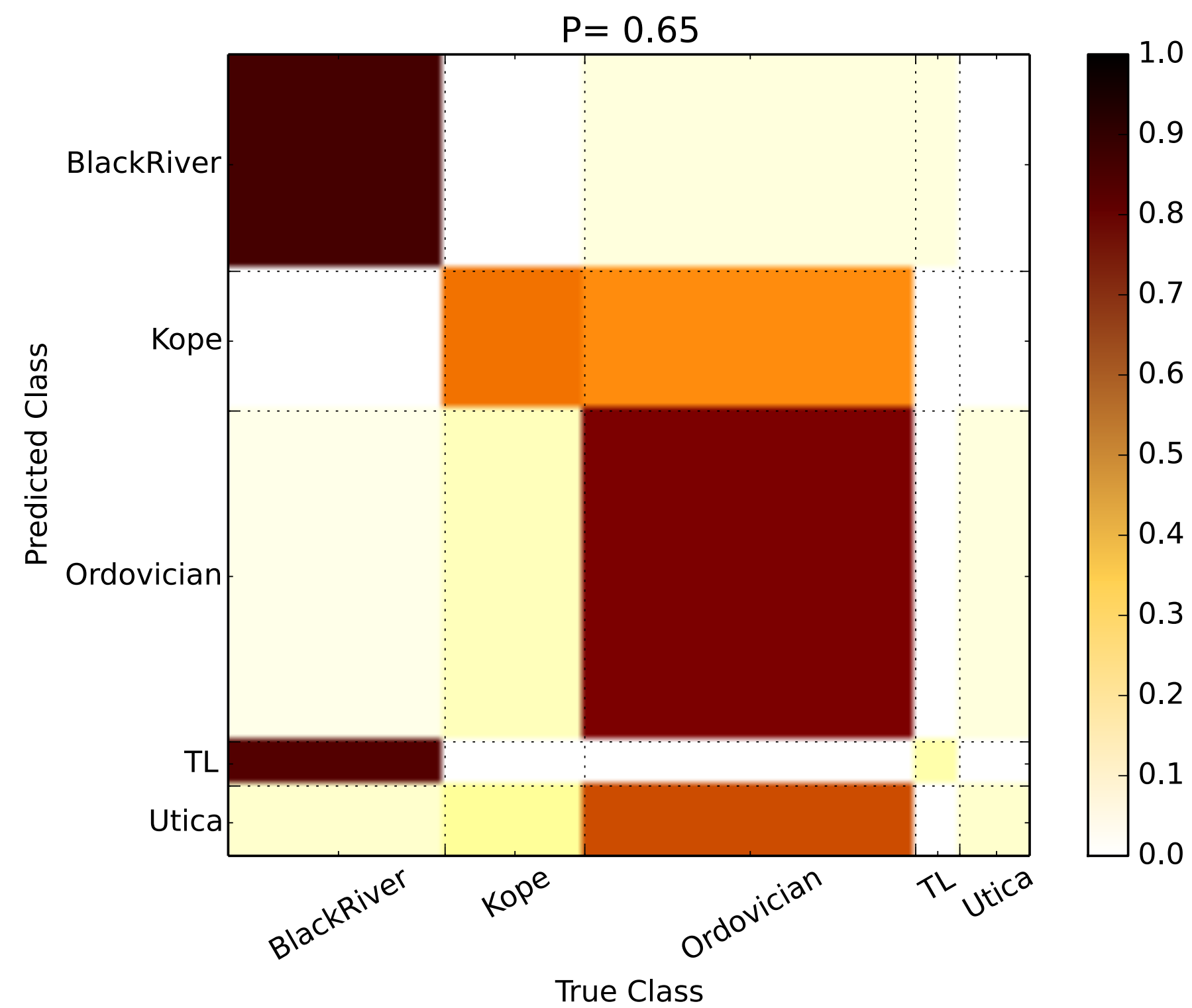


Figure from Trenton Black River Project [3]

Conclusions

Can stratigraphic units be classified by fractal statistics?

- In some instances..... Yes.... kind of maybe?
- A lot of confusion on how stratigraphic units are labelled and how their formations might be related (more geology).

Is the scattering transform a useful tool for geo-fractal analysis?

- On a very limited dataset, the scattering transform showed encouraging results.
- Has deep ties to rigorous multifractal analysis
- More work on when it is statistically valid

Future work

More data, more input from geology

My main interest is in seismic applications

- Classification of depth slices
- Use for constraints in waveform inversion methods
- Potential use as a seismic attribute

References

- [1] **Deep Scattering Spectrum**, Andén J. and Mallat. S., Submitted to IEEE Transactions on Signal Processing, 2011
- [2] **Interesting pursuits in seismic curvature attribute analysis**, Chopra, S. and K. J. Marfurt CSEG RECORDER, 2011
- [3] **Trenton Black River Project**, <http://www.wvgs.wvnet.edu/www/tbr/>